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14. ABSTRACT
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AN UPDATE ON THE AFIT PULSED POWER PROGRAM

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Abstract

The AFIT pulsed power program began in June of 1979. Since then, three classes have graduated, resulting in 15 officers receiving MSEE degrees with specialization in pulsed power systems. During the past two years, substantial changes have been made to the curriculum due to changes in the AFIT faculty and suggestions from Air Force Laboratory personnel and previous graduates. This paper describes the changes in the curriculum and highlights some of the thesis research performed by the students.

Introduction

The Air Force Institute of Technology (AFIT) offers both university level degree programs as well as professional continuing and professional specialized education courses and programs. To meet Air Force needs, AFIT offers resident degree programs in curricula for which an Air Force environment (including specialized facilities) is particularly beneficial or which are not available in civilian institutions. One such program is the pulsed power systems sequence.

In 1978, the Air Force Weapons Laboratory (AFWL) asked AFIT to develop a program which would lead to the award of a Master of Science in Electrical Engineering with specialization in pulsed power systems. A committee, including AFIT, AFWL, and Air Force Wright Aeronautical Laboratory (AFWAL) personnel, was formed to develop a curriculum which would satisfy the requirements of the AFIT School of Engineering and the Department of Electrical Engineering while educating the student in the specific topics required to specialize in pulsed power systems.

The School of Engineering requires the student to present 48 quarter hours of required graduate courses and approved graduate electives for the award of the Master of Science degree. Twelve of the 48 hours are awarded upon successful completion by the student of an independent investigation of a problem of interest to the Air Force (or DOD agency), the results of which have been presented to the major department as a formal thesis. The normal graduate electrical engineering program is six academic quarters (18 months) in length and begins with the summer quarter. Since the students are Air Force officers with no other duties, they are expected to maintain an average load of 12 quarter hours or 72 quarter hours for the program. Specific requirements of the Department of Electrical Engineering are that the student's program include two approved "sequences" of courses, two graduate mathematics courses, and two technical communications courses. A sequence of courses is a set of courses (normally 16-20 quarter hours plus any prerequisites) which provides the student with enough depth to pursue an independent study in that area. These requirements provide the framework around which the pulsed power systems program was developed.

Pulsed Power Program

The pulsed power systems sequence is normally the student's primary sequence; however, it has been used as a second sequence by several students from the graduate electro-optics program (which is conducted jointly by the Engineering Physics and EE departments). The sequence consists of five, four quarter hour courses. In addition a two course (4 quarter hours each) sequence in electromagnetics is required of all pulsed power students. Current descriptions of these seven courses are shown below.

Course Descriptions

EE 5.14, "Energy Conversion and Storage." The course begins with a review of magnetic circuits followed by detailed coverage of the properties of ferromagnetic and permanent magnet materials. Materials with special applications such as METGLAS are considered. Transformers (particularly pulse transformers), the energy conversion process, energy storage capacitors, and inductive storage are covered in detail. The course stresses fundamental principles from an applications standpoint.

EE 6.07, "Lightning and Electromagnetic Pulse Modeling." A study of the modeling techniques which are used to understand the effects of lightning and electromagnetic pulse (EMP). Topics covered include lightning and EMP phenomenology, electric and magnetic fields produced by lightning and EMP, current distribution in lightning and EMP channels, aircraft lightning and EMP interaction, effects of lightning and EMP in transmission lines, sensor designs for lightning and EMP, power spectrum levels for lightning and EMP. The course emphasizes the practical aspects of the problems.

EE 6.08, "Pulsed Power Electronics." This course explores techniques for analysis and design of the power circuits of solid state power converters. Topics include circuits with switches and diodes, power semiconductor switches, controlled rectifiers, and inverters. Power supplies and charging circuits for pulsed power systems are also considered. Emphasis is on the high speed, high power requirements of military pulsed power systems.

EE 6.09, "Special Topics in Pulsed Power Systems." The course culminates the pulsed power sequence and will present current state of the art topics in the pulsed power area. Topics will generally be selected from the Proceedings of the IEEE International Pulsed Power Conference and the Power Modulator Symposia. System aspects such as safety and control circuitry are considered by examining representative systems.

EE 6.38, "High Voltage Engineering." Major components of high voltage, pulsed power systems are analyzed. After an initial survey of fundamental physical concepts (basic atomic concepts, breakdown, glow discharge, corona, and arcing), three major classes of components and subsystems are discussed. First a variety of opening and closing switches, including tubes, spark gaps, solid state switches, and magnetic switches are covered. Next high voltage generators, including Marx banks and Blumleins are analyzed. The third class of components includes pulse forming networks, modulators, and other pulse forming techniques. The course concludes with a survey of high voltage measurement techniques.

EE 5.23, "Electric and Magnetic Fields." The electrostatic and magnetostatic solutions to Maxwell's equations are developed in rectangular, cylindrical, and spherical coordinate systems. The effects of

material bodies, conducting, dielectric, and ferromagnetic materials are considered. The quasis-static solution to Maxwell's equations are used to introduce the complete form of Maxwell's equations.

EE 5.24, "Electromagnetic Waves I." The course begins with the study of propagation of voltage and current on ideal and lossy transmission lines. Maxwell's equations are presented and solved in both time and frequency domains. Special cases include plane wave propagation, reflection and refraction, metallic and dielectric waveguides, and cavities. The fundamental concepts of microwave circuits are presented.

Summary of Curriculum Changes

The above courses represent a shift in emphasis of the pulsed power program. The original pulsed power sequence contained six courses, three of which were heavily devoted to the design of transformers and synchronous machines. In addition one fields course was optional. Graduates of the first two classes and laboratory personnel identified fields and high voltage phenomena as requiring more emphasis in the program.

The current program includes two fields courses as well as the lightning/EMP course. To allow the inclusion of these courses, two of the machine design courses were replaced and the third (EE 5.14) was revised to cover several energy storage and conversion methods. High voltage phenomena was added to EE 6.38 by moving several topics to the power electronics course. Also several lectures were devoted to high voltage measurement principles. This year a two quarter hour special studies course devoted to pulsed power measurement techniques will be included in the curriculum.

The final course in the sequence (EE 6.09) has also changed considerably. Originally the course consisted primarily of a group design project. It has evolved into a somewhat more structured course which attempts to bring together the material from the other courses in two ways. First, some of the holes in the other courses can be filled and more depth can be provided. Secondly, applications of pulsed power as part of a system are studied.

Second Sequence

In the original program, all students were required to take digital control theory as their second sequence. Currently students are allowed to take any of the sequences approved by the EE department. Since they are already required to take two fields courses, a number of students elect to complete the fields sequence. Other choices include control theory and electro-optics systems. This flexibility allows the students to customize the program to their interests while providing some diversity among the graduates.

Thesis

The heart of the AFIT Masters degree program is the student's thesis effort. It is normally spread over the last three academic quarters with the fifth quarter being devoted exclusively to thesis research. In the pulsed power program, the students have been encouraged to choose topics which require them to spend the quarter at a DOD laboratory working on a project of interest to the agency. To date students have worked at the AFWL, AFWAL, the Army MERADCOM at Ft Belvoir, and the Army ERADCOM at Ft Monmouth (Evans). Funding for the students' travel expense comes from the laboratory and/or funds provided by DNA for the AFIT pulsed power program.

Last year, four students worked on projects involving fused opening switches, explosive opening switches, and battery power supplies for railguns. The results of these studies have been reported at this conference. This year, five students are working on projects involving modeling of flux diffusion in magnetocumulative generators (MCGs), development of a series detonator scheme for MCGs, modification and testing of a repetitive opening switch for inductive energy storage circuits, and computer simulation of an electromagnetic gun system including a fast start turbine and homopolar generator. Potential thesis topics (hardware or software oriented) are welcome at any time and may be submitted directly to the author.

Summary

The AFIT pulsed power program has changed from one which emphasized prime power and power conditioning to one which provides the student with a relatively broad background in pulsed power. Changes to the program include the addition of two electromagnetic fields courses, a lightning and EMP course, and an introduction to high voltage phenomena and measurement techniques. Thesis topics are selected from proposals submitted by various DOD agencies and often require the student to spend one academic quarter at a laboratory performing "hands on" research.

Three graduate EE classes have graduated since the pulsed power program began in the summer of 1979. Included among the graduates are 15 Air Force officers and one Army officer with specialization in pulsed power systems. Four additional students will graduate in December 1983. About half of the Air Force officers have been assigned to positions requiring the pulsed power specialty, the remainder being assigned in their second sequence or to a general EE slot. All appear to be doing well in their assignments.

References

1. P. Joseph and T. Skvarenina, "An Evaluation of Battery Power Supplies for Electric Railguns," paper 2.2, this conference.
2. J. Bueck, "The Effects of Cryogenic Initial Temperatures on Aluminum and Copper Electrically Exploded Foil Fuses," paper 9.4 this conference.
3. J. Watson, M. Hines, R. Reinovsky, and P. Levi, "Staged Explosively Drive Opening Switch Development for Magnetic Flux Compression Generators," paper 36.2 this conference.